AD-A074 403 TRACOR INC AUSTIN TX F/G 9/2

ESTIMATION OF COMPUTER REQUIREMENTS FOR A DETECTION TECHNIQUE B--ETC(U)

MAR 68 H A REEDER NOBSR-93352

UNCLASSIFIED TRACOR-68-352-U

1 OF 1

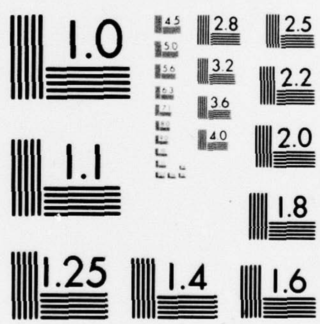
AD A074403

END

DATE FILMED

10-79

DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Contract NObsr-93352
Project Serial SF001-03-16
Task 8523
TRACOR Project 002 016 01
Document Number 68-352-U

MOST Project -3

LEVEL

TECHNICAL MEMORANDUM

ESTIMATION OF COMPUTER REQUIREMENTS FOR A DETECTION TECHNIQUE BASED ON SEQUENTIAL HYPOTHESIS TESTING

by

H. A. Reeder

Submitted to:

Commander, Naval Ship Systems Command
Department of the Navy
Washington, D. C. 20360

Attn: Mr. Joe Manseau, Code 00V1C

1 March 1968

TRACOR

6500 Tracor Lane, Austin, Texas 78721, AC 512/926-2800

TRACOR 6500 TRACOR LANE, AUSTIN, TEXAS 78721

15

Contract NObsr-93352
Project Serial SF001-03-16
Task 8523
TRACOR Project 002 016 01
~~Document Number~~ 68-352-U
14 TRACOR

9

TECHNICAL MEMO~~RANDUM~~

6

ESTIMATION OF COMPUTER REQUIREMENTS FOR A DETECTION TECHNIQUE BASED ON SEQUENTIAL HYPOTHESIS TESTING

by

10 Hugh A. Reeder

Submitted to:

Commander, Naval Ship Systems Command
Department of the Navy
Washington, D. C. 20360

Attn: Mr. Joe Manseau, Code 00V1C

12 28p.

11

1 March 1968

16 F00103

17 SF00103 16

Approved by:

W. C. Moyer
W. C. Moyer
Program Manager

Submitted by:

Hugh A. Reeder
Hugh A. Reeder
Project Director

352100

TRACOR 6500 TRACOR LANE, AUSTIN, TEXAS 78721

ABSTRACT

The computer storage and execution time requirements necessary to implement a detection and tracking technique based on sequential hypothesis testing have been examined. Mathematical expressions which relate these requirements to sonar system parameters and the detection algorithm parameters are derived. It is shown that the technique can be implemented on modest, state-of-the-art digital computers. In addition, future studies designed to increase the shipboard utility of the detection and tracking technique are discussed.

TABLE OF CONTENTS

Section		Page
ABSTRACT		i
TABLE OF CONTENTS		ii
1.	INTRODUCTION	1
1.1	Purpose	1
1.2	Background	1
2.	COMPUTER REQUIREMENTS	4
2.1	Introduction	4
2.2	Design Parameters	4
2.2.1	Sonar Parameters	4
2.2.2	Decision and Tracking Parameters	5
2.3	Average Number of Status Units Required	6
2.4	Example	11
2.5	Actual Storage Requirements	13
2.6	Average Number of Computer Instructions Required	14
3.	FURTHER THEORETICAL STUDIES	17
3.1	Limiting Computer Storage and Execution Time	17
3.2	Shipboard Considerations	18
3.3	Areas to be Studied in the Immediate Future	19
4.	PERFORMANCE EVALUATION	20
5.	CONCLUSIONS	21
6.	REFERENCES	22

1. INTRODUCTION

1.1 PURPOSE

The formulation of a computer aided detection technique has been described in a recent technical memorandum.[1] This technique is based on sequential hypothesis testing. The technique employs a digital computer to examine in real time the output of a sonar system, reduce the volume of data, perform ping-to-ping integration, and generate useful displays. A question of immediate practical interest concerns the computer storage and execution time requirements necessary to implement this technique for shipboard usage. The purpose of this memorandum is to illustrate how computer requirements can be estimated and how the sonar system parameters affect the computer requirements.

In addition to these practical considerations, a discussion of theoretical problems requiring future study is given. These problem areas are directly related to shipboard utilization of the likelihood ratio processor.

1.2 BACKGROUND

The sequential hypothesis testing procedure considered in this note is discussed in Ref. 1. Briefly the procedure is a method of deciding between two hypotheses H_0, a track is noise, and H_1, a track is signal-plus-noise. The quantity tested is the logarithm of the likelihood ratio, the ratio of the probability density function associated with H_1 to the probability density function associated with H_0. Two decision thresholds for the logarithm of the likelihood ratio are derived from assigned probabilities of wrong decisions: a lower threshold below which it is assumed that the track is noise and is rejected, and an upper threshold above which it is assumed that a track is a target and is displayed. For samples between the two thresholds information is retained and combined with results of succeeding ping cycles until the joint likelihood ratio crosses the upper or lower threshold.

The data flow, shown in Fig. 1, begins with the output of the sonar processor entering a Preliminary Data Reduction section where, after thresholding, a single ping event package containing a position vector and the log likelihood ratio of the event is created. The reduced output continues to the New/Status Linkage section where possible linkages with previously established tracks contained in the status file are considered. For each event in the status file four functional quantities are maintained: a) the position vector in the preceeding echo cycle, b) the predicted position vector in the present echo cycle, c) a position variance vector, and d) the log likelihood ratio of the event. If the position vector of a single ping event from the Preliminary Data Reduction section lies in a volume defined by the expected position vector and variance vector of an event in the status file, a linkage is considered. If the combined log likelihood ratio is greater than the lower decision threshold, a new status unit is created and stored in a new status file.

The reduced sonar output from the Preliminary Data Reduction also goes to the Secondary Data Reduction section where the log likelihood ratio of the single ping event is tested. If this is above the lower decision threshold, a new status unit is created and stored in a new status file.

The status file from the previous echo cycle is processed by the Status Data Reduction section. The purpose of this reduction is to maintain well established tracks even though on one echo the new data does not pass the lower threshold test. The log likelihood ratio of each entry in the status file is degraded and, if it is still above the lower decision threshold, a new entry is created and stored in a new status file.

The final process is carried out by examining the log likelihood ratios of the newly created status units. Those that exceed the upper decision threshold are appropriately displayed to the operator.

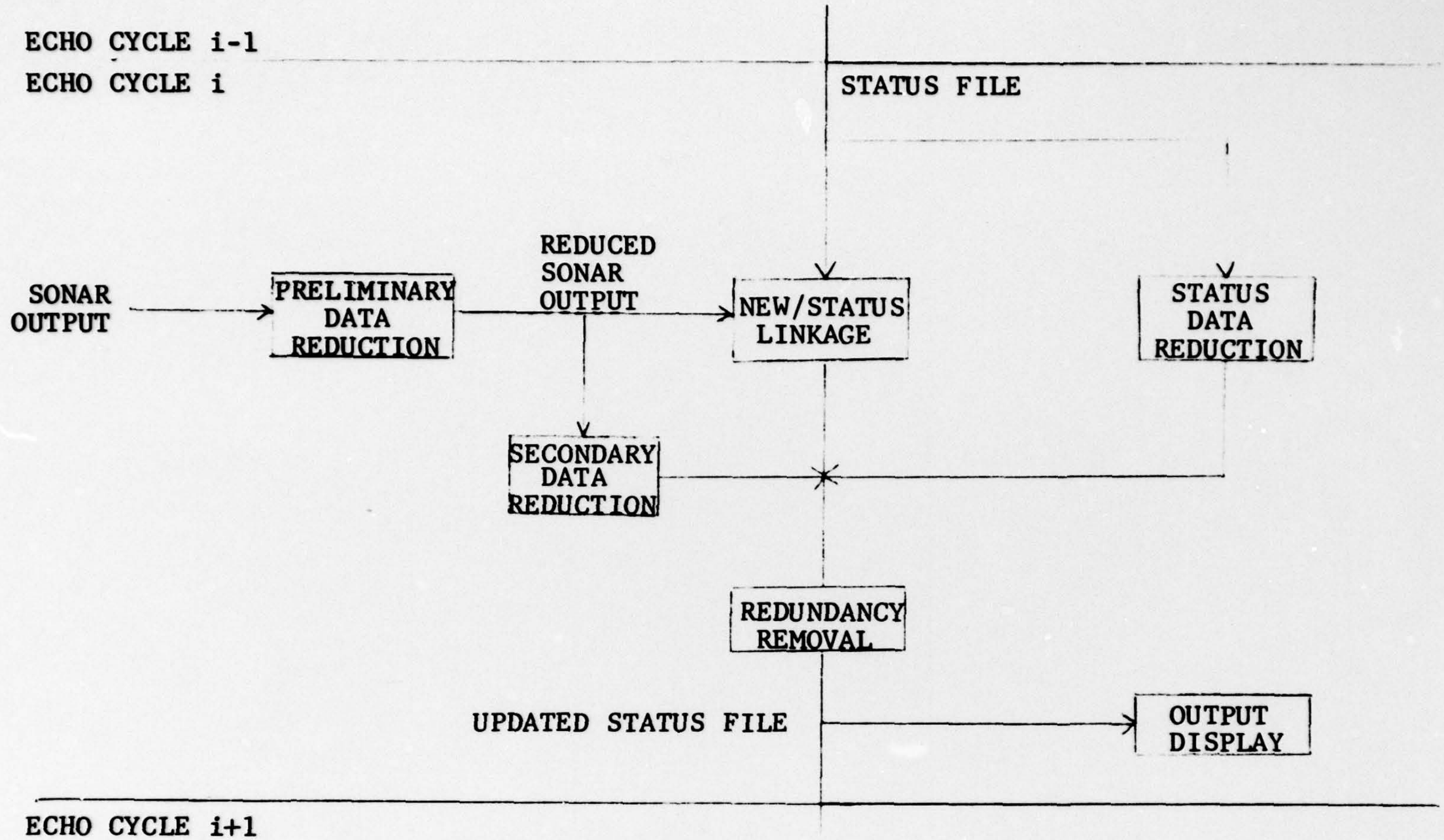


FIG. 1 - GENERAL ORGANIZATION OF LOGIC AND DATA FLOW

2. COMPUTER REQUIREMENTS

2.1 INTRODUCTION

Prime considerations in implementing a likelihood ratio processor for shipboard usage are the computer storage and execution time requirements. These requirements are determined to a large extent by certain design parameters. This section lists the pertinent parameters and relates these parameters to a theoretical procedure for estimating computer requirements. Numerical examples are included.

2.2 DESIGN PARAMETERS

The basic design parameters which should be taken into consideration when implementing the computer process are:

1. The output statistics of the sonar signal processor in the presence of noise and signal-plus-noise and the output bandwidth of the sonar processor.
2. The time between pings.
3. The number of dimensions with which possible targets are to be tracked (range, bearing, Doppler, etc.).
4. The number of resolution cells in each dimension.
5. The size of a resolution cell in each dimension.
6. The dynamic constraints on the rate of change of each dimension.
7. The desired display clutter rate.
8. The minimum signal-to-noise ratio of interest.

These eight items will be divided into two categories, sonar parameters and decision parameters, and are discussed in the next two sections.

2.2.1 Sonar Parameters

Since the sequential testing procedure is a statistical test, it is not surprising that the output statistics of the

sonar processor are the most important factor in determining computer requirements. The output statistics of noise alone and signal-plus-noise must be known in order to calculate the likelihood ratio and certain probabilities of the sequential test continuing. Although it is easier to manipulate the probability density functions if they are in a closed form, a tabulated function can be used with the aid of a digital computer.

The output bandwidth of the sonar is a factor in determining, among other things, the rate of independent samples to be expected. This, in turn, has a bearing on the number of samples to be allowed for each range or time resolution cell.

The time between pings when compared to the program execution time determines whether the process will work in real time or not.

2.2.2 Decision and Tracking Parameters

The total number of resolution cells is of prime importance. This number is given by the product of the number of resolution cells allowed in each dimension. Some possible dimensions are range, bearing or beam number, and Doppler. The number of range resolution cells is given by the time period searched, usually the time between pings, divided by the time of passage of a sonar signal through a range resolution cell.

The maximum dynamic range allowed in any dimension is given by the product of the number of resolution cells in that dimension and the size of each cell.

Another factor which affects computer loading is the maximum rate of change allowed for a target's movements in each dimension. This is reflected in the allowable size of the variance vector in each dimension. The present procedure uses two fixed variances: a large one associated with single ping events allowing for any reasonable opening or closing range rate

and a smaller one associated with linked tracks allowing for variations in the observed range rate. The size of these variances affects the number of linkages to be made.

The most important result obtained by this process is to have a high probability of detection with a low clutter rate. The clutter rate is affected by the specified probabilities of terminating the sequential testing procedure with an incorrect decision and the design signal-to-noise ratio specified to determine the log likelihood ratio.

For a specified minimum detectable signal-to-noise ratio, a design signal-to-noise ratio should be chosen such that a sample of the minimum signal-to-noise ratio will be assigned a log likelihood ratio value of zero. If this is done, then there will be a .5 probability of detection for a track with that average signal-to-noise ratio.

2.3 AVERAGE NUMBER OF STATUS UNITS REQUIRED

The objective of this section is to derive a formula for the average number of status units created in one ping cycle by the sequential testing procedure outlined above. It is assumed that the procedure has been operating in a noise only environment long enough to reach a steady-state condition, that is, as many status units are being created as discarded. The assumption of noise only is not unreasonable since a true target track would produce one status unit and possibly a few status units describing branching noise tracks.

By considering the output statistics of the sonar processor, it is possible to find the probability, P_I, of an independent sample exceeding a specified lower threshold T corresponding to the one in the Preliminary Data Reduction section. It is assumed that the maximum independent sample in a resolution cell will be chosen. The probability that at least one of the N_I independent samples in the cell will exceed the threshold T is given by

$$P_I = 1 - (1 - p_I)^{N_I} \quad . \qquad (1)$$

As was pointed out before, the total number of resolution cells, N_R, is given by the product of the number of resolution cells in each dimension.

The calculation of the number of status units created or continued in a single ping will be divided into three parts. The first source is from the Secondary Data Reduction section. The next two will be from the New/Status Linkage section, but one source will consider only the linkage of single ping events, and the other, linkages of tracks with two or more samples or events.

Another possible source of status units is the Status File Reduction section of the processor. This section is mainly to propagate strong tracks that have perhaps not linked in the present ping cycle. Since only noise is being considered, this section will not contribute many status units.

For any sample x_i taken from a resolution cell, a likelihood ratio $L(x_i)$ is formed by

$$L(x_i) = \frac{p_1(x_i)}{p_0(x_i)} \ , \qquad (2)$$

where $p_1(x_i)$ is the probability density function for signal-plus-noise and $p_0(x_i)$ is the probability density function for noise alone. If $L(x_i)$ is greater than B, the lower decision threshold, a status unit will be formed by the Secondary Data Reduction section. The probability P_1, that the status unit will be formed is given by

$$P(B < L(x_i)) = \int_{L^{-1}(B)}^{\infty} p_0(x)\ dx \ , \qquad (3)$$

$$P_1 = 1 - \left(1 - P(B < L(x_i))\right)^{N_I} \quad . \tag{4}$$

The probability that a status unit will not be formed is, of course, $1 - P_1$; hence, the number of status units N_1 formed is a binominally distributed random variable with mean

$$\overline{N}_1 = N_R \cdot P_1 , \tag{5}$$

and standard deviation

$$\sigma_{N_1} = \sqrt{N_R \; P_1 \; (1 - P_1)} \quad . \tag{6}$$

The next source of status units to be considered is the linkage of status units representing single ping events of the previous ping cycle. The probability P_2 that the likelihood ratio will be greater than the lower decision threshold after two samples, x_1, x_2, have been considered is given by

$$P_2 = P[L(x_1,x_2) > B \mid x_1 > T, L(x_1) > B, x_2 > T], \tag{7}$$

or

$$P_2 = \frac{\int_S\int \; p_0(x_1) \; p_0(x_2) \; dx_2 \; dx_1}{P_1 P_T}, \tag{8}$$

where the region S is defined by the conditions

$$T < x_1 < \infty$$
$$T < x_2 < \infty$$
$$B < L(x_1) < \infty$$
$$B < L(x_1,x_2) < \infty \quad .$$

On the average the number N_2 of status units created by single ping events linking with noise peaks will be

$$\overline{N}_2 = \overline{N}_1 \cdot (N_L P_T) \cdot P_2 , \qquad (9)$$

and the standard deviation

$$\sigma_{N_2} = \sqrt{N_1 \cdot N_L P_T \cdot P_2(1 - P_2)} \quad . \qquad (10)$$

The last source of status units is tracks that represent at least two samples. To find the number of these it is necessary to know how many samples, on the average, it takes to reach a decision that the track represents noise. The direct computation of this number is a complex procedure; however, by certain approximations[2] it is possible to find a good value for the average sample number of all possible tests*. Let N_{av} be the average number of samples to reach a decision when noise alone is present. Formally N_{av} is given by

$$N_{av} = \sum_{i=1}^{\infty} i \cdot p_i , \qquad (11)$$

where p_i is the probability that the test will end on the ith sample.

If N'_{av} is the average number of samples for tests that have more than two samples, then

*The probability density function to be used in determining the average sample number is

$$p'(x) = \frac{d}{dX} P(x < X \mid T < x) = \frac{d}{dX} \frac{P(T < x < X)}{P(T < x)}$$

$$= p(x)/P(t < x) \qquad T < x$$

$$= 0 \qquad \text{otherwise} \quad .$$

$$N_{av} = \frac{P_1 P_2}{P_T} \cdot N'_{av} + 1 \cdot (1 - \frac{P_1}{P_T}) + 2 \cdot (\frac{P_1}{P_T})(1 - P_2) , \quad (12)$$

or

$$N'_{av} = (N_{av} - 1 - \frac{P_1}{P_T})/P_2 + 2 . \quad (13)$$

By simulating the sequential testing procedure on a computer, it is possible to calculate an estimate of the standard deviation of N'_{av}. For the examples considered below the estimate was on the order of .5 when N'_{av} was in the range of 3 to 4.

The average number of status units which have been linked in established tracks can be expressed as

$$\overline{N}_3 = \overline{N}_2 \cdot (N_S \cdot P_T) \cdot (N'_{av} - 2) , \quad (14)$$

where N_S is the number of resolution cells in the small variance vector. The density function of N'_{av} is not known; hence, the standard deviation of N_3 cannot be found. It seems reasonable, however, to proceed as in N_1 and N_2 and assign a value to the standard deviation of N_3 as follows

$$\sigma_{N_3} = \sqrt{N_2 \; (N_S \cdot P_T) \; \sigma^2_{N'_{av}}} \; . \quad (15)$$

If N_R and $N_R N_L P_T^2$ are large, the binomial distributions may be approximated by Gaussian distributions with the given means and standard deviations. The average total number of status units for steady-state noise only conditions is

$$\overline{N}_{tot} = \overline{N}_1 + \overline{N}_2 + \overline{N}_3 , \quad (16)$$

with standard deviation of

$$\sigma_{N_{tot}} = \sqrt{\sigma_{N_1}^2 + \sigma_{N_2}^2 + \sigma_{N_3}^2} \quad . \tag{17}$$

2.4 EXAMPLE

The example to be considered is the same as discussed in Ref. 1 with the additional consideration of a multibeam case. The sonar processor consists of a linear correlator followed by an envelope detector. The bandwidth is 100 Hz. There are 1500 range resolution cells and in the multibeam case, five beams. The time between pings is assumed to be 15 sec. The large fixed variance for single ping event status units is ±20 range resolution cells to accommodate targets with range rates of ±20 knots and smaller range variance of ±2 cells to allow a variation of ±2 knots in the observed range rate. In the multibeam case the beam variance is ±1 in both cases. In determining the decision threshold the probability of accepting a noise track as a target is assumed to be 0.001 and that of rejecting a target to be 0.05. Since only normalized Gaussian noise is present, the output statistics $p_o(x)$ are Rayleigh:

$$p_o(x) = \frac{x}{N^2} e^{-\frac{x^2}{2N^2}} , \tag{18}$$

where N is the rms value of the noise before envelope detection. The likelihood ratio is given in Ref. 1 as

$$L(x) = I_o(x\ S/N^2)\ \exp(-S^2/2N^2) \quad . \tag{19}$$

In that report a linear approximation of the logarithm of the likelihood ratio $\ell(x)$ is derived as

$$\ell(x) = ax + b, \tag{20}$$

where

$$a = (S/N - 1/6.74)/N\,,$$

$$b = 3.87\ S/N - \tfrac{1}{2}(S/N)^2 - \tfrac{1}{2}\log(7.75\pi\ S/N) - a \cdot 3.87N\ .$$

Using Eq. (20) it is relatively easy to find bounds of the random variables when computing P_1 and P_2. Since each resolution cell will contain one independent sample,

$$P_1 = \int_{\frac{\log B - b}{a}}^{\infty} p_o(x)\ dx\,, \tag{21}$$

and

$$P_2 = \int_{\frac{\log B - b}{a}}^{\infty} \int_{\max\left(\frac{\log B + \log E_P N_L - 2b}{a} - x_1,\,T\right)}^{\infty} p_o(x_1)\ p_o(x_2)\ dx_2\ dx_1\ . \tag{22}$$

In the case considered $T = \frac{\log B - b}{a}$; hence $P_T = P_1$. For the single beam case with design S/N of 12 dB,

$$P_1 = .213$$

$$P_2 = .120$$

$$n'_{av} = 3.5$$

and for the multibeam case,

$$P_1 = .213$$

$$P_2 = .0628$$

$$n'_{av} = 3.2\ .$$

The average number of status units N_{tot} is 744 and 7149, respectively, with standard deviations of 23.3 and 58.4, respectively. If the design S/N is lowered to 6 dB, the average number becomes 2,481 and 20,070 with standard deviations of 35.6 and 72.3, respectively.

2.5 ACTUAL STORAGE REQUIREMENTS

The total number of status units given above does not give the true computer storage requirements. It is necessary to find the number of computer words required to describe each status unit, which contains a position vector from the preceding echo cycle, the expected position vector in the next echo cycle, a variance vector, and the joint log likelihood ratios of the event.

A position vector can include range, Doppler, and bearing. If 2048 or less range resolution cells are allowed, then 11 binary bits will describe the range. If 16 beam and 16 Doppler cells are allowed, then 4 bits each will suffice. Hence the position vector from the preceding echo cycle and the expected position vector for the next echo cycle require 2(11+8) = 38 bits. The variance vector associated with the expected position vector can only take on discrete values; therefore, an indicator of 3 bits is all that is necessary to tell the program which variance vector to use. The likelihood ratio can be represented by a scaled integer number of 12 bits, giving 3 significant decimal digits.

For the multibeam case with Doppler information a total of 53 bits of information is required for a status unit. If the fixed word length of a computer, like the AN/USQ-20A, is 30 bits, the first word could contain the present beam, Doppler, and range, the variance indicator and the predicted beam, and Doppler all presented in 30 bits. The first 11 bits of the second word could contain the predicted range and the last 12

bits the likelihood ratio. There would be 7 bits unused; hence a total of two computer words are required for each status unit.

The process as it is now programmed requires two status file storage areas of equal size, one for the previous status file and one for the file being created. The total storage requirements are obtained by multiplying the total number of status units N_{tot} by 4.

The numerical results of the example given show that for some values of the design parameters of interest the storage requirements can be met by a modest, state-of-the-art computer. By appropriate changes in programming and storage allocation a wider range of design parameters might possibly be accommodated.

2.6 AVERAGE NUMBER OF COMPUTER INSTRUCTIONS REQUIRED

If the storage requirements for the status file are within reason for the computer being considered, the next question which arises is the expected execution time. This depends on the number of computer instructions to be carried out during a ping cycle which is, in turn, related to the number of status units being created. To find the number of instructions required, the processing of the ping cycle will be separated into three parts, the Secondary Data Reduction, the New/Status Linkage, and the Status File Reduction. The count of instructions will vary from computer to computer depending on the instructions available. The numbers quoted here are based on the machine language listing of a research program written in UNIVAC FORTRAN V. Speed and storage were sacrificed where necessary to obtain flexibility. Careful machine language programming would reduce the number of required instructions.

For each single ping event out of the Preliminary Data Reduction section the Secondary Data Reduction section requires I_1 instructions

$$I_1 = I_1' + (P_1/P_T)I_1'' \tag{23}$$

$$= 9 + (P_1/P_T)22 ,$$

where I_1' is the number of instructions to decide whether the single ping event should form a status unit or not, and I_1'' is the number of instructions to create a status unit.

In the New/Status Linkage the number of instructions required for each sample from the Preliminary Data Reduction section is approximately

$$I_2 = I_2' + \frac{2N_L \overline{N}_{tot}}{N_R} I_2'' + \frac{\overline{N}_2 + \overline{N}_3}{N_R P_T} I_2''' \tag{24}$$

$$= 38 + \frac{2N_L \overline{N}_{tot}}{N_R} \cdot 29 + \frac{\overline{N}_2 + \overline{N}_3}{N_R P_T} 80 ,$$

where I_2' is the number of instructions for each entry, I_2'' is the number required to consider linkages, I_2''' is the number required to create a new status unit.

The number of instructions required for the Status File Reduction section is

$$I_3 = \overline{N}_{tot} \cdot I_3' \tag{25}$$

$$= \overline{N}_{tot} \cdot 73 ,$$

where I_3' is the number of instructions to consider whether to propagate an established track. Again, the numbers I_1', I_1'', I_2', I_2'', I_2''', and I_3' are based on the requirements of the current FORTRAN program.

Since the total number of input samples from the Preliminary Data Reduction section is $N_S = N_R P_T$, the total number of instructions to be expected for each ping cycle is

$$I_{tot} = N_R P_T(I_1 + I_2) + I_3 \quad . \tag{26}$$

If T_I is the execution time of a computer instruction, the total execution time, T_{tot}, is

$$T_{tot} = T_I \cdot I_{tot} \quad . \tag{27}$$

For examples given above using a T_I of 8 microseconds, the instruction execution time for an AN/USQ-20A computer, the number of instructions and execution times for various design parameters are

Beam	Design S/N (dB)	N_{tot}	I_{tot}	T_{tot} (sec)
Single	12	744	408,284	3.27
Single	6	2,481	2,331,636	18.65
Multi	12	7,149	9,776,219	78.21
Multi	6	20,070	50,736,557	405.89

The above execution times for the AN/USQ-20A do not look promising. However, it should be emphasized that the count of the number of instructions to execute various parts of the processor is based on a machine language compilation of a research-oriented FORTRAN program. When adapting the process to a particular computer it is possible to streamline the coding and thereby decrease the program execution time. Moreover, modern computers have greatly reduced execution times; execution times of one microsecond are not uncommon with present generation computers*. If the execution time for one instruction is one microsecond, all but the last case will run in real time.

*A present military version of the UNIVAC 1230 computer has a core memory storage in excess of 30,000 words and an execution time of 1.8 microseconds.

3. FURTHER THEORETICAL STUDIES

3.1 LIMITING COMPUTER STORAGE AND EXECUTION TIME

The previous sections show that lowering the design signal-to-noise ratio has a marked tendency to increase the required storage and execution time, and it is natural to ask how these requirements might be limited or reduced. One or a combination of the following study areas may furnish means of reducing computer storage and execution time without degrading the detection of targets.

1. Adaptive Adjustment of the Threshold in the Preliminary Data Reduction Section. This would allow only enough new single ping events into the sequential processor to keep storage near the maximum. This would be the simplest process to implement, but it introduces the possibility that small target peaks may not get into the computer.

2. Periodically Updating the Design Signal-to-Noise Ratio. An increase in this parameter would reduce the number of status units in the status file. The effect of this on the decision process must be studied as well as the method of implementing it.

3. Rejection of Multiple Linkages. The present processor allows more than one track to share the same peak in a ping cycle, each track having a different predicted position vector. If only the linkage with the greatest log likelihood ratio were retained, the number of status units would be decreased.

4. Linkages Based on Other Clues. The computer processor may be made more selective by applying other clues to the tracking or decision algorithms. For example, the Doppler information of a sample could be compared with track range rate and, if consistent, a linkage made. If aspect information is available, then it could be applied.

5. Modified Log Likelihood Ratio. An interesting variation to the sequential test would be to choose a linear function of the sonar output that would give a specified average number of samples for a decision in the presence of noise and for a signal with the design signal-to-noise ratio. Since the likelihood ratio sequential test is optimum, any variation from it would be sub-optimum in the overall system; however, the degradation may be small and the benefits, faster rejection of noise and integration of signal-plus-noise target tracks, could outweigh the degradation.

6. Adaptive Testing. Two methods[3,4] of adaptive sequential testing have been developed recently. While not limiting computer storage, they would allow the computer processor to adapt to the changing conditions of the target or the sea. The feasibility of implementing these methods should receive attention.

3.2 SHIPBOARD CONSIDERATIONS

The above areas explore ways of improving the internal processes of the sequential detector. There are other items which must be considered before a useful system can be implemented on a ship. These are:

1. Tracking Procedures. A realistic system must adjust the predicted position vectors contained in the status units when the ship is changing course and speed. The manner in which this is done depends on the coordinate system used by the sequential detection process.

2. Additional Target Information. The computer should certainly be able to handle duties other than detection. The position vectors of a status unit for the last several pings should be available for display if the log likelihood ratio is large enough. Also, range rate, Doppler, course, and speed should be available for display purposes. Storage of multiple

ping information will, of course, increase computer requirements.

3. Clutter Rate. The display clutter rate and the probability of detection as a function of the design parameters should be studied. The display threshold will be one parameter studied.

3.3 AREAS TO BE STUDIED IN THE IMMEDIATE FUTURE

It is doubtful that all the areas outlined above can be accomplished under the present contract. Emphasis will be placed on the following areas.

1. Adaptive Adjustment of the Threshold in the Preliminary Data Reduction. The threshold adjustment will be based on the number of status units created in a ping cycle. The threshold may be adjusted once each cycle or periodically during the cycle. The effect of this adjustment on detection and the algorithm for the adjustment will be studied.

2. Tracking Procedures. The most promising tracking coordinate system appears to be polar coordinates relative to own ship's course. This system can be modified to take into account own ship's maneuvers by adding a correction vector to each position vector in the status file. How often this updating is necessary and exactly how to calculate the correction vector are subjects for further study.

3. Linkages Based on Doppler. The most promising way to make the computer processor more selective in retaining linkages would be to use Doppler information to decide the observed range rate is consistent with the Doppler information. Doppler information would also allow range rate information to be applied to single ping events, thus the window widths (variances) may be decreased in this case. Both the probability density functions involved and the implementation algorithm will be studied in detail.

4. PERFORMANCE EVALUATION

Once the major practical difficulties relating to the feasibility of shipboard implementation have been resolved, it would be most desirable to conduct a thorough performance evaluation of the sequential likelihood ratio processor. It is generally felt that sequential likelihood ratio processing offers certain advantages over standard signal processing techniques such as single-ping matched filtering. Two of these advantages are a reduction in the amount of extraneous data presented to the operator, and ping-to-ping integration. In order to demonstrate that these advantages translate into improved system performance, the following tests should be conducted.

The performance of a typical active sonar detection system should be measured in terms of receiver operating characteristic (ROC) curves. To do this, typical ping cycles would be synthesized and applied to a signal processor such as a linear correlator. The correlator output would then be thresholded and applied to a display such as the simulated AN/SQS-26 B-scan. (This display has been simulated in the TRACOR display facility for an AN/SQS-26 mutual interference study.) By conducting observer tests with the display it would be possible to obtain ROC curves for the simulated detection system.

Next, a sequential likelihood ratio processor implemented on a shipboard type computer such as the AN/USQ-20 (or a simulated version thereof) should be inserted between the signal processor and the display. Observer tests would be conducted and new ROC curves obtained. In this way, the gains in overall system performance arising from the use of sequential likelihood ratio processing could be measured in a quantitative fashion.

5. CONCLUSIONS

Expressions which relate computer storage requirements and program execution time to parameters of a sonar system and the likelihood ratio processor have been derived. The numerical results indicate the processing technique can be implemented on a modest, state-of-the-art digital computer. For less advanced computers such as the AN/USQ-20, the likelihood ratio processor can be implemented with some restrictions imposed on the processor decision and tracking parameters. Theoretical analyses for the immediate future will be aimed at modifications to the existing algorithms such that computer requirements will be minimized.

6. REFERENCES

1. Reeder, H. A., "Computer Utilization of Sequential Hypothesis Testing for Detection and Classification of Sonar Signals," TRACOR Document No. 67-717-U, 7 December 1967.

2. Mood, A. and F. Graybil, Introduction to the Theory of Statistics, McGraw-Hill, New York.

3. Nolte, L. W., "Theory of Signal Detectability: Adaptive Optimum Receiver Design," Journal of the Acoustical Society of America, Vol. 42, No. 4, 1967, p. 773.

4. Fu, K. S. and Y. T. Chien, "Sequential Recognition Using Non-Parametric Ranking Procedure," IEEE TRANS. on INFORMATION THEORY, Vol. II-3, No. 3, 1967, p. 484.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) TRACOR, Inc. 6500 Tracor Lane Austin, Texas 78721	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
"ESTIMATION OF COMPUTER REQUIREMENTS FOR A DETECTION TECHNIQUE BASED ON SEQUENTIAL HYPOTHESIS TESTING"

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Memorandum

5. AUTHOR(S) (Last name, first name, initial)
Reeder, Hugh A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1 March 1968	22	4

8a. CONTRACT OR GRANT NO. NObsr-93352 b. PROJECT NO. SF001-03-16 c. Task 8523 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 68-352-U 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ship Systems Command Department of the Navy Washington, D. C. 20360

13. ABSTRACT

The computer storage and execution time requirements necessary to implement a detection and tracking technique based on sequential hypothesis testing have been examined. Mathematical expressions which relate these requirements to sonar system parameters and the detection algorithm parameters are derived. It is shown that the technique can be implemented on modest, state-of-the-art digital computers. In addition, future studies designed to increase the shipboard utility of the detection and tracking technique are discussed.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
__________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
__________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
__________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Security Classification